EXHIBIT 17

SIXTH EDITION

LOCAL & METROPOLITAN AREA NETWORKS

Gigabit Ethernet

Wireless LANs

Switched Ethernet

LAN QoS

Storage Area Networks

WILLIAM STALLINGS

LOCAL AND METROPOLITAN AREA NETWORKS

SIXTH EDITION

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CHAPTER 1

INTRODUCTION

The local area network (LAN) has come to play a central role in information distribution and office functioning within businesses and other organizations. The major factors driving the widespread use of LANs have been the proliferation of personal computers, workstations, and servers, coupled with the increasing reliance on the client/server computing model.

With the dropping price of LAN hardware and software, LANs have become more numerous and larger, and they have taken on more and more functions within the organization. The upshot is that the LAN, once installed, quickly becomes almost as essential as the telephone system. At the same time, there is a proliferation of LAN types and options and a need to interconnect a number of LANs at the same site and with LANs at other sites. This has led to the development of LANs of higher and higher data rates and the relatively recent introduction of the metropolitan area network (MAN).

Before defining the terms LAN and MAN, it is useful to look at the trends responsible for the importance of these networks, which we do in the first section. Next we contrast the differences among LANs, MANs, and wide area networks (WANs). This is followed by a discussion of key application areas for LANs and MANs. This chapter also provides pointers to Internet resources relating to LANs and MANs.

1.1 THE NEED FOR LOCAL NETWORKS

Perhaps the driving force behind the widespread use of LANs and MANs is the dramatic and continuing decrease in computer hardware costs, accompanied by an increase in computer hardware capability. Year by year, the cost of computer systems continues to drop dramatically while the performance and capacity of those systems continue to rise equally dramatically. At a local warehouse club, you can pick up a personal computer for less than $1000 that packs the wallop of an IBM mainframe from 10 years ago. Inside that personal computer, including the microprocessor and memory and other chips, you get over 100 million transistors. You can't buy 100 million of anything else for so little. That many sheets of toilet paper would run more than $100,000.

Thus we have virtually "free" computer power. And this ongoing technological revolution has enabled the development of applications of astounding complexity and power. For example, desktop applications that require the great power of today's microprocessor-based systems include

- Image processing
- Speech recognition
- Videoconferencing
- Multimedia authoring
- Voice and video annotation of files

Workstation systems now support highly sophisticated engineering and scientific applications, as well as simulation systems, and the ability to apply workgroup

principles to image and video applications. In addition, businesses are relying on increasingly powerful servers to handle transaction and database processing and to support massive client/server networks that have replaced the huge mainframe computer centers of yesteryear.

All of these factors lead to an increased number of systems, with increased power, at a single site: office building, factory, operations center, and so on. At the same time, there is an absolute requirement to interconnect these systems to

- Share and exchange data among systems
- Share expensive resources

The need to share data is a compelling reason for interconnection. Individual users of computer resources do not work in isolation. They need facilities to exchange messages with other users, to access data from several sources in the preparation of a document or for an analysis, and to share project-related information with other members of a workgroup.

The need to share expensive resources is another driving factor in the development of networks. The cost of processor hardware has dropped far more rapidly than the cost of mass storage devices, video equipment, printers, and other peripheral devices. The result is a need to share these expensive devices among a number of users to justify the cost of the equipment. This sharing requires some sort of client/server architecture operating over a network that interconnects users and resources.

1.2 LANs, MANs, AND WANs

LANs, MANs, and WANs are all examples of communications networks. A communications network is a facility that interconnects a number of devices and provides a means for transmitting data from one attached device to another.

There are a number of ways of classifying communications networks. One way is in terms of the technology used: specifically, in terms of topology and transmission medium. That approach is explored in Chapter 4. Perhaps the most commonly used means of classification is on the basis of geographical scope. Traditionally, networks have been classified as either LANs or WANs. A term that is sometimes used is the MAN.

Figure 1.1 illustrates these categories, plus some special cases. By way of contrast, the typical range of parameters for a multiple-processor computer is also depicted.

Wide Area Network

WANs have traditionally been considered to be those that cover a large geographical area, require the crossing of public right-of-ways, and rely at least in part on circuits provided by a common carrier. Typically, a WAN consists of a number of interconnected switching nodes. A transmission from any one device is routed through these internal nodes to the specified destination device.

Traditionally, WANs have provided only relatively modest capacity to subscribers. For data attachment, either to a data network or to a telephone network

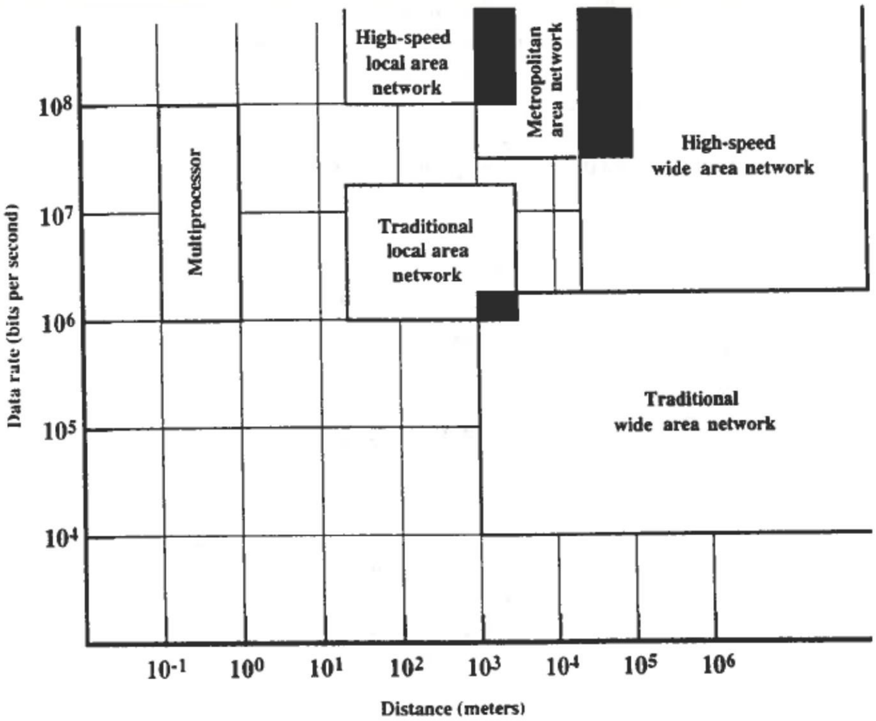

Figure 1.1 Comparison of Multiprocessor Systems, LANs, MANs, and WANs

by means of a modem, data rates of 9600 bps or even less have been common. Business subscribers have been able to obtain higher rates, with a service known as T1, which operates at 1.544 Mbps, being common. The most important recent development in WANs in this range of performance has been the development of the integrated services digital network (ISDN), which provides circuit-switching and packet-switching services at rates up to 1.544 Mbps (2.048 Mbps in Europe).

The continuing development of practical optical fiber facilities has led to the standardization of much higher data rates for WANs, and these services are becoming more widely available. These high-speed WANs provide user connections in the 10s and 100s of Mbps, using transmission techniques known as frame relay and asynchronous transfer mode (ATM).

Local Area Network

As with WANs, a LAN is a communications network that interconnects a variety of devices and provides a means for information exchange among those devices. There are several key distinctions between LANs and WANs:

1. The scope of the LAN is small, typically a single building or a cluster of buildings. This difference in geographic scope leads to different technical solutions, as we shall see.

2. It is usually the case that the LAN is owned by the same organization that owns the attached devices. For WANs, this is less often the case, or at least a significant fraction of the network assets are not owned. This has two implications. First, care must be taken in the choice of LAN, since there may be a substantial capital investment (compared to dial-up or leased charges for WANs) for both purchase and maintenance. Second, the network management responsibility for a LAN falls solely on the user.
3. The internal data rates of LANs are typically much greater than those of WANs.

LANs have been the focus of a standardization effort by the IEEE 802 committee, and it is useful to review the IEEE definition of a LAN (Table 1.1).

A Simple LAN

A simple example of a LAN that highlights some of its characteristics is shown in Figure 1.2. All of the devices are attached to a shared transmission medium. A transmission from any one device can be received by all other devices attached to the same network.

What is not apparent in Figure 1.2 is that each device attaches to the LAN through a hardware/software module that handles the transmission and medium access functions associated with the LAN. Typically, this module is implemented as a physically distinct network interface card (NIC) in each attached device. The NIC contains the logic for accessing the LAN and for sending and receiving blocks of data on the LAN.

An important function of the NIC is that it uses a buffered transmission technique to accommodate the difference in the data rate between the LAN medium

Table 1.1 Definitions of LANs and MANs*

The LANs described herein are distinguished from other types of data networks in that they are optimized for a moderate size geographic area such as a single office building, a warehouse, or a campus. The IEEE 802 LAN is a shared medium peer-to-peer communications network that broadcasts information for all stations to receive. As a consequence, it does not inherently provide privacy. The LAN enables stations to communicate directly using a common physical medium on a point-to-point basis without any intermediate switching node being required. There is always need for an access sublayer in order to arbitrate the access to the shared medium. The network is generally owned, used, and operated by a single organization. This is in contrast to Wide Area Networks (WANs) that interconnect communication facilities in different parts of a country or are used as a public utility. These LANs are also different from networks, such as backplane buses, that are optimized for the interconnection of devices on a desk top or components within a single piece of equipment.
A MAN is optimized for a larger geographical area than a LAN, ranging from several blocks of buildings to entire cities. As with local networks, MANs can also depend on communications channels of moderate-to-high data rates. Error rates and delay may be slightly higher than might be obtained on a LAN. A MAN might be owned and operated by a single organization, but usually will be used by many individuals and organizations. MANs might also be owned and operated as public utilities. They will often provide means for internetworking of local networks. Although not a requirement for all LANs, the capability to perform local networking of integrated voice and data (IVD) devices is considered an optional function for a LAN. Likewise, such capabilities in a network covering a metropolitan area are optional functions of a MAN.

* From IEEE 802 Standard, *Local and Metropolitan Area Networks: Overview and Architecture*, 1990.

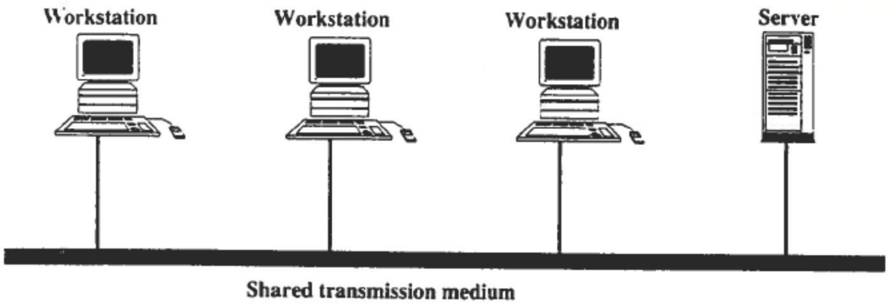

Figure 1.2 Simple Local Area Network

and the NIC-processor link, as illustrated in Figure 1.3. The NIC captures transmissions intended for the attached device, which arrive at the data rate of the LAN, which may be, for example, 10 Mbps. When a block of data is captured, it is stored temporarily in an input buffer. It is then delivered to the host processor, often over some sort of backplane bus, at the data rate of that bus. This data rate is typically different from the LAN data rate. For example, it may be 50 or 100 Mbps. Thus the NIC acts as an adapter between the data rate on the host system bus and the data rate on the LAN.

High-Speed LANs

Traditional LANs have provided data rates in a range from about 1 to 20 Mbps. These data rates, though substantial, have become increasingly inadequate

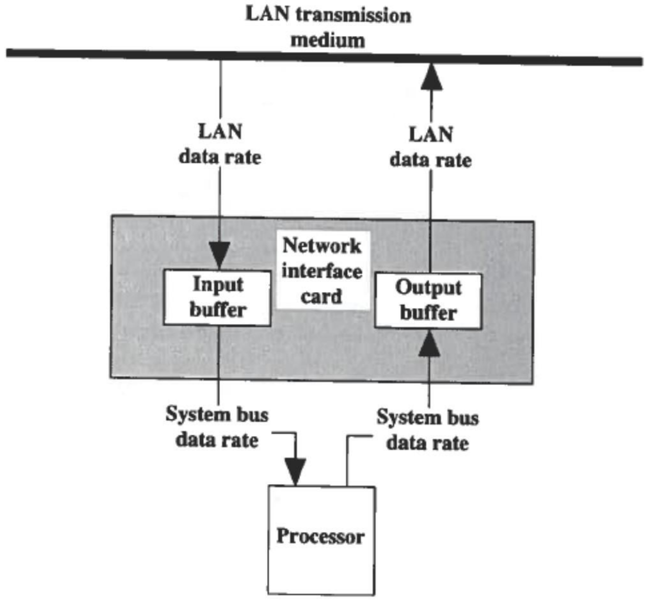

Figure 1.3 Buffered Transmission through a Network Interface Card

with the proliferation of devices, the growth in multimedia applications, and the increased use of the client/server architecture. As a result, much of the effort in LAN development has been in the development of high-speed LANs, with data rates of 100 Mbps or more. In later chapters, we will see a number of examples of high-speed LANs.

Metropolitan Area Networks

As the name suggests, a MAN occupies a middle ground between LANs and WANs. Interest in MANs has come about as a result of a recognition that the traditional point-to-point and switched network techniques used in WANs may be inadequate for the growing needs of organizations. While frame relay and ATM promise to meet a wide range of high-speed needs, there is a requirement now for both private and public networks that provide high capacity at low costs over a large area. The high-speed shared-medium approach of the LAN standards provides a number of benefits that can be realized on a metropolitan scale. As Figure 1.1 indicates, MANs cover greater distances at higher data rates than LANs, although there is some overlap in geographical coverage.

The primary market for MANs is the customer that has high-capacity needs in a metropolitan area. A MAN is intended to provide the required capacity at lower cost and greater efficiency than obtaining an equivalent service from the local telephone company.

1.3 APPLICATIONS OF LANS AND MANS

The variety of applications for LANs and MANs is wide. To provide some insight into the types of requirements that LANs and MANs are intended to meet, this section provides a brief discussion of some of the most important general application areas for these networks.

Personal Computer Local Networks

A common LAN configuration is one that supports personal computers. With the relatively low cost of such systems, individual managers within organizations often independently procure personal computers for departmental applications, such as spreadsheet and project management tools, and Internet access.

But a collection of department-level processors will not meet all of an organization's needs; central processing facilities are still required. Some programs, such as econometric forecasting models, are too big to run on a small computer. Corporate-wide data files, such as accounting and payroll, require a centralized facility but should be accessible to a number of users. In addition, there are other kinds of files that, although specialized, must be shared by a number of users. Further, there are sound reasons for connecting individual intelligent workstations not only to a central facility but to each other as well. Members of a project or organization team need to share work and information. By far the most efficient way to do so is digitally.

Certain expensive resources, such as a disk or a laser printer, can be shared by all users of the departmental LAN. In addition, the network can tie into larger corporate network facilities. For example, the corporation may have a building-wide LAN and a wide area private network. A communications server can provide controlled access to these resources.

LANs for the support of personal computers and workstations have become nearly universal in organizations of all sizes. Even those sites that still depend heavily on the mainframe have transferred much of the processing load to networks of personal computers. Perhaps the prime example of the way in which personal computers are being used is to implement client/server applications.

For personal computer networks, a key requirement is low cost. In particular, the cost of attachment to the network must be significantly less than the cost of the attached device. Thus, for the ordinary personal computer, an attachment cost in the hundreds of dollars is desirable. For more expensive, high-performance workstations, higher attachment costs can be tolerated. In any case, this suggests that the data rate of the network may be limited; in general, the higher the data rate, the higher the cost.

Backend Networks and Storage Area Networks

Backend networks are used to interconnect large systems such as mainframes, supercomputers, and mass storage devices. The key requirement here is for bulk data transfer among a limited number of devices in a small area. High reliability is generally also a requirement. Typical characteristics include the following:

- **High data rate:** To satisfy the high-volume demand, data rates of 100 Mbps or more are required.
- **High-speed interface:** Data transfer operations between a large host system and a mass storage device are typically performed through high-speed parallel I/O interfaces, rather than slower communications interfaces. Thus, the physical link between station and network must be high speed.
- **Distributed access:** Some sort of distributed medium access control (MAC) technique is needed to enable a number of devices to share the medium with efficient and reliable access.
- **Limited distance:** Typically, a backend network will be employed in a computer room or a small number of contiguous rooms.
- **Limited number of devices:** The number of expensive mainframes and mass storage devices found in the computer room generally numbers in the tens of devices.

Typically, backend networks are found at sites of large companies or research installations with large data processing budgets. Because of the scale involved, a small difference in productivity can mean millions of dollars.

Consider a site that uses a dedicated mainframe computer. This implies a fairly large application or set of applications. As the load at the site grows, the existing mainframe may be replaced by a more powerful one, perhaps a multiprocessor system. At some sites, a single-system replacement will not be able to keep up;

PART TWO LAN/MAN Architecture

Part Two surveys the key technology elements that are common to all types of LANs and MANs, including topology, transmission medium, medium access control, and logical link control.

CHAPTER 4 TOPOLOGIES AND TRANSMISSION MEDIA

The essential technology underlying all forms of LANs and MANs comprises topology, transmission medium, and medium access control technique. Chapter 4 examines the first two of these elements. Four topologies are in common use: bus, tree, ring, and star. The most common transmission media for local networking are twisted pair (unshielded and shielded), coaxial cable (baseband and broadband), optical fiber, and wireless. The chapter closes with a discussion of structured cabling systems.

CHAPTER 5 PROTOCOL ARCHITECTURE

Chapter 5 introduces the protocols needed for stations attached to a LAN to cooperate with each other in the exchange of data. Specifically, the chapter provides an overview of link control and medium access control protocols. The use of bridges and routers to interconnect LANs is also introduced.

CHAPTER 6 LOGICAL LINK CONTROL

Logical link control (LLC) is the highest layer that is specifically part of the LAN/MAN protocol architecture. It is used above all of the medium access control (MAC) standards. The primary purpose of this layer is to provide a means of exchanging data between end users across a link or a collection of LANs interconnected by bridges. Different forms of the LLC service are specified to meet specific reliability and efficiency needs. After a discussion of these services, Chapter 6 deals with some of the key mechanisms of link control protocols. Finally, the specific LLC protocols are examined.